HCAT
U.S. - CANADIAN
HARD CHROME ALTERNATIVES TEAM

SERDP PP1151 - ID Plasma Spray

HCAT Program Review
Cocoa Beach, Fl
December 2000

ROWAN TECHNOLOGY GROUP
Linking Global Technologies with Markets

Keith Legg 847-680-9420

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Technical objective

- **To demonstrate proof-of-principle for the plasma spray method:**
  - Improve ability to spray in constricted areas; miniature gun and process modifications
  - Understand limits, improve coating performance and reliability
  - Improve underlying science and technology of plasma spray
  - Improve coating properties by use of small and nano-agglomerate particles
  - Feed results into follow-on dem/val as soon as possible for use in new weapons platforms (e.g. JSF) and maintenance of existing systems

Technical background

- HVOF thermal spray coatings (primarily WC-Co) on ODs have proved superior to electrolytic hard chrome
  - Less wear and fatigue - “lifetime coatings” in some cases
  - Lower life-cycle cost
- Wide variety of wear-resistant materials to meet diverse needs
  - WC-Co meets most needs
  - Tribaloy and stainless steel for lower wear applications
- But HVOF cannot be used in IDs < about 11”
- Use of plasma and arc spray growing for IDs
  - Not yet developed enough for high pressure landing gear hydraulics or for IDs < 3” (e.g. actuators)

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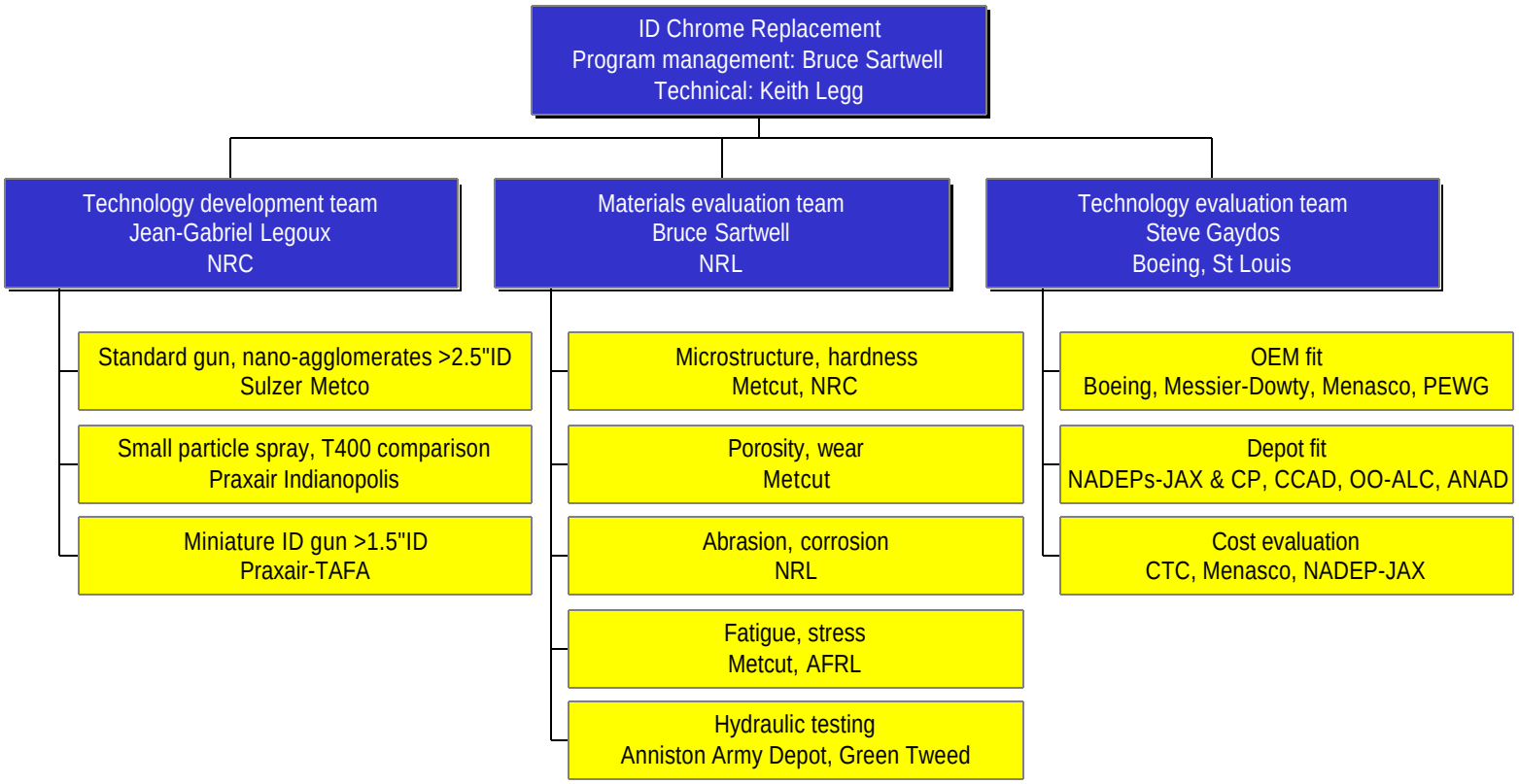
Team


ID Chrome Replacement
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Technical: Keith Legg
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Jean-Gabriel Legoux
NRC
Materials evaluation team
Bruce Sartwell
NRL
Technology evaluation team
Steve Gaydos
Boeing, St Louis
Standard gun, nano-agglomerates >2.5"ID
Sulzer Metco
Small particle spray, T400 comparison
Praxair Indianopolis
Miniature ID gun >1.5"ID
Praxair-TAFA
Microstructure, hardness
Metcut, NRC
Porosity, wear
Metcut
Abrasion, corrosion
NRL
Fatigue, stress
Metcut, AFRL
Hydraulic testing
Anniston Army Depot, Green Tweed
OEM fit
Boeing, Messier-Dowty, Menasco, PEWG
Depot fit
NADEPs-JAX & CP, CCAD, OO-ALC, ANAD
Cost evaluation
CTC, Menasco, NADEP-JAX

Technical Approach - Summary of Technology Development approach

	Praxair-TAFA	Praxair Indianapolis	Sulzer Metco	NRC
Equip-ment	 Praxair 2700 miniature 30kW, 1.5” ID		 Sulzer Metco F-100 20 kW 4” ID  Sulzer Metco F-210 12kW, 2.5” ID	All guns Characterize performance – velocity and temperature profiles
Powder	Standard WC-Co Small particles Nano-agglomerates	Tribaloy 400 WC-Co small particles	Standard WC-Co powders Nano-agglomerate WC-Co	All powders Optimize spray conditions Consider other materials
Issues	How small a diameter can we coat? And with what type of powder?	Do small particles provide better quality?	Best conditions for large parts – landing gear outer cylinders Do nanoparticles give better particles? – OSH issues	Characterize coatings and coated tubes Evaluate OSH issues of nanopowders

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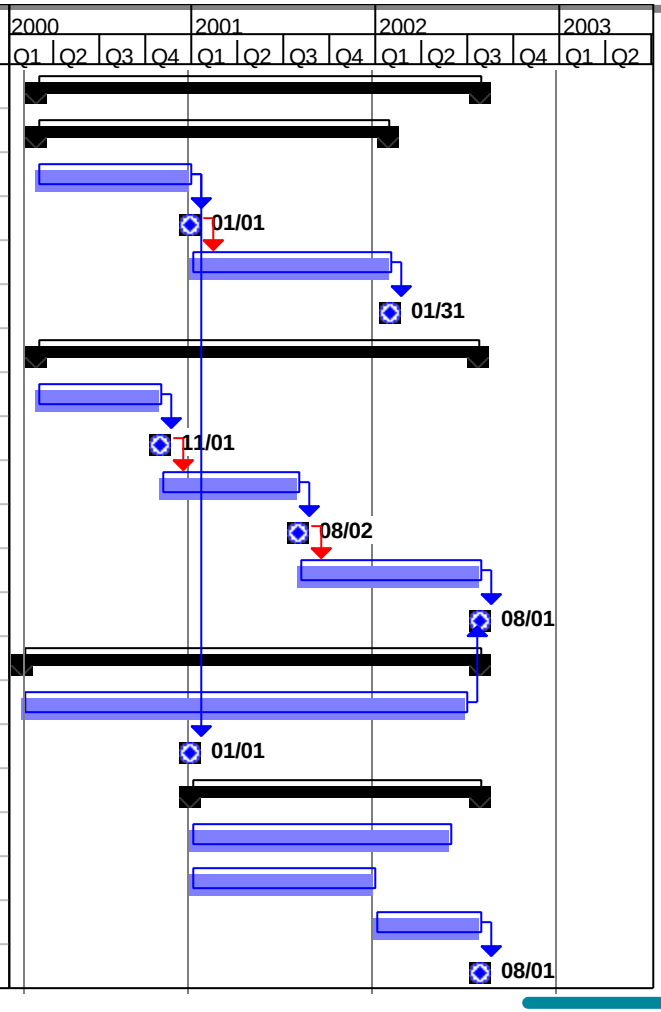
Overall plan - technical

ID	Task Name
2	**Task 1. Technology/process development**
3	**Task 1.1 Standard ID gun, small particles**
4	Process development
5	Gun outputs characterized
6	Additional testing
7	Go/no go on small/nano particle use
8	**Task 1.2 Miniature ID gun**
9	Plasma gun test, modification
10	Miniature gun preparation complete
11	Small/nanopowder process dev.
12	Go/no go for miniature gun
13	Performance testing
14	Technology/material suitability decision
15	**Task 2. Materials evaluation**
16	Task 2.1 Coating, substrate properties
17	Initial measurements complete. Go/no go on technology
18	**Task 2.2 Coating performance**
19	Fatigue
20	Wear, corrosion
21	Hydraulic testing
22	Performance suitability decision



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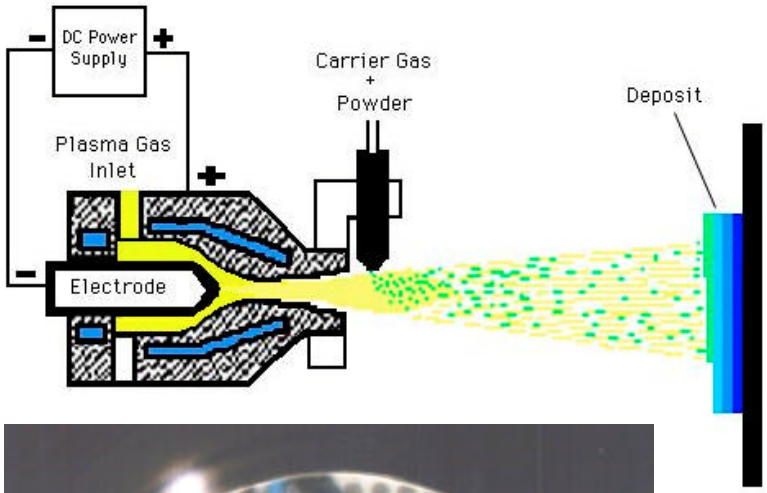
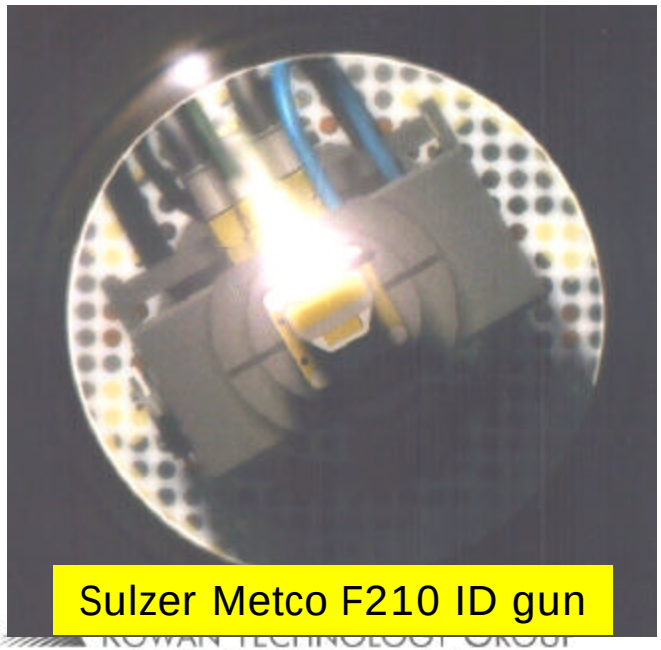
Technical background





Sulzer Metco F210 ID gun

- Powder particles injected into plasma plume accelerate, heat, soften, splat onto surface
- Typical particle size - 50µm
- Typical coating thickness - 0.001” - 0.020”
- Hardness - 1,000 - 1,500 HV (EHC is 800 - 1,000 HV)
- Coating rate high - landing gear inner cylinder OD typically takes 20 min

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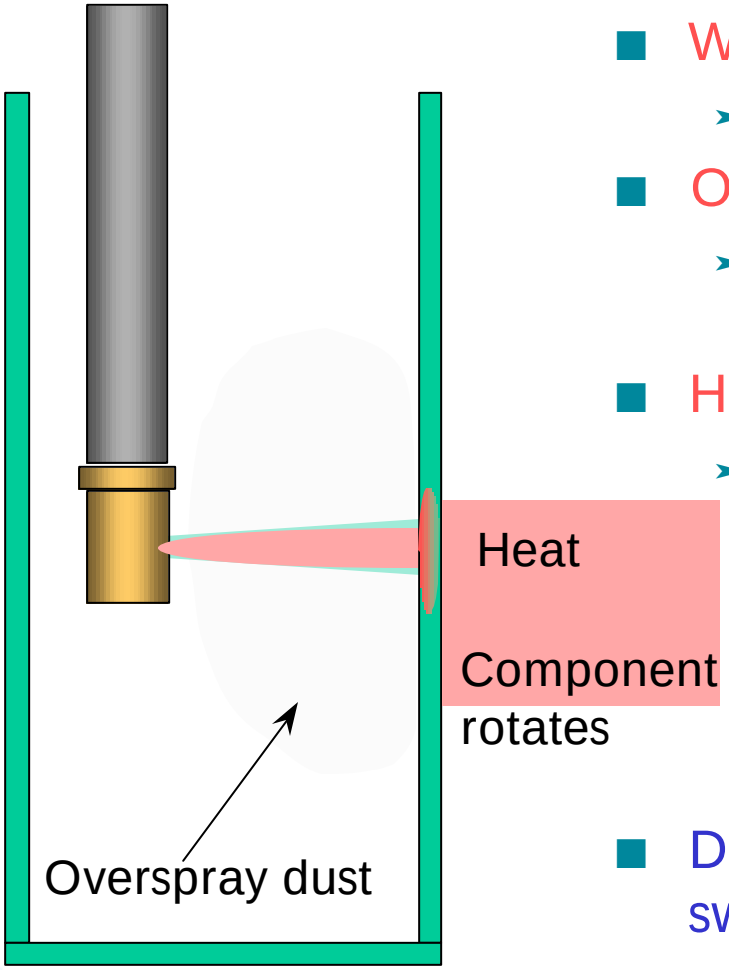
Technical approach - critical issues



- What is smallest ID we can coat?
  - Smallest gun, standoff, best particles
- Overspray dust incorporation
  - Porosity
    - additional gas flow to remove particles
- Heat removal
  - Overheat component
    - additional gas flow to remove heat
    - minimize plasma power
      - reduces powder overheating
      - allows smaller particles
        - less porosity, smoother
- Design internal gas flow to cool and sweep out particles

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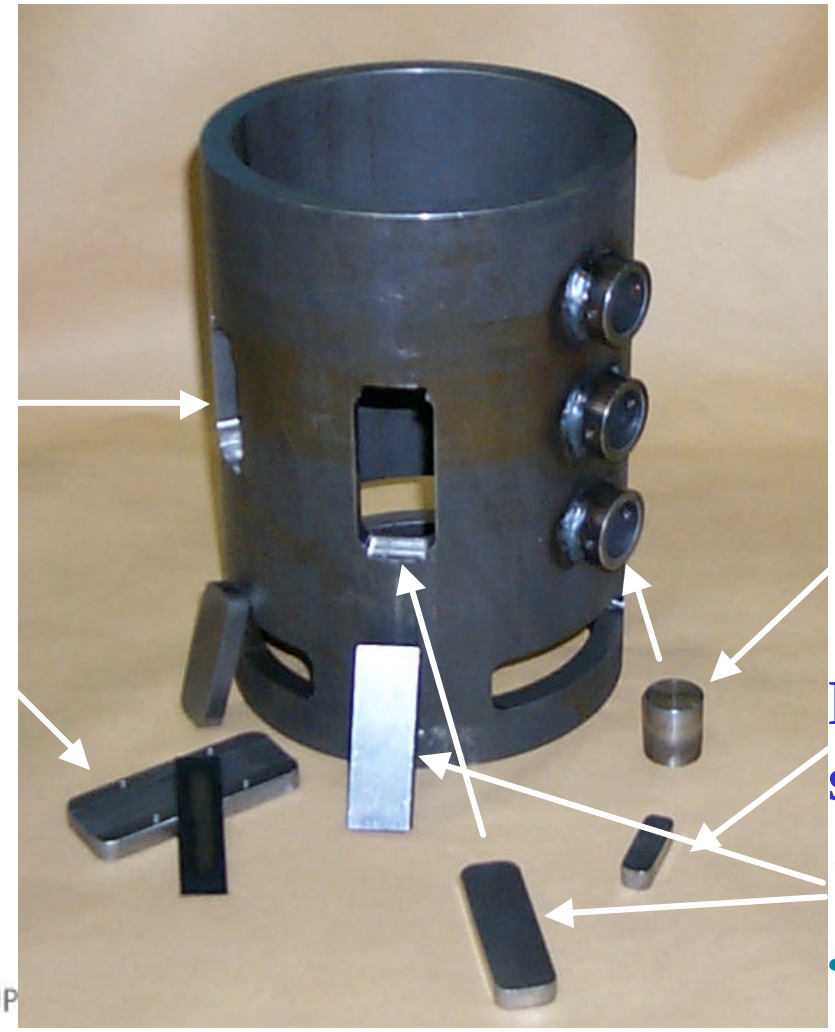
Specimen Holder Simulating ID - NRC, Montreal



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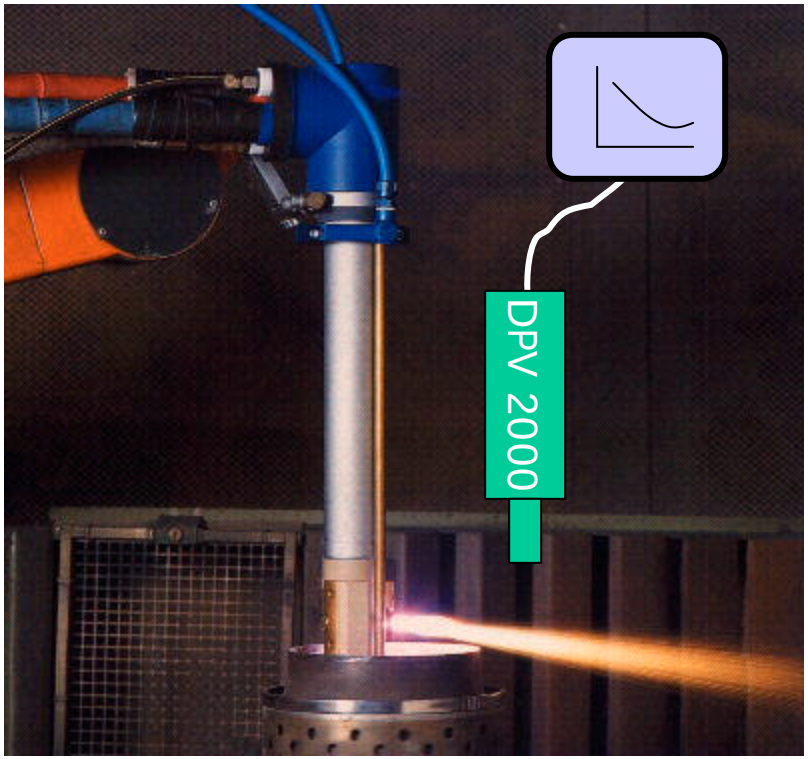
Initial testing - NRC

- Initial aim to feel out the process and limitations of standard spray conditions and powders
- 3 WC-17Co powders sprayed with Sulzer Metco F-100 gun
  - Used for larger IDs (>4”)
- DPV 2000 spray monitor
  - Measures particle temperature and velocity along spray jet



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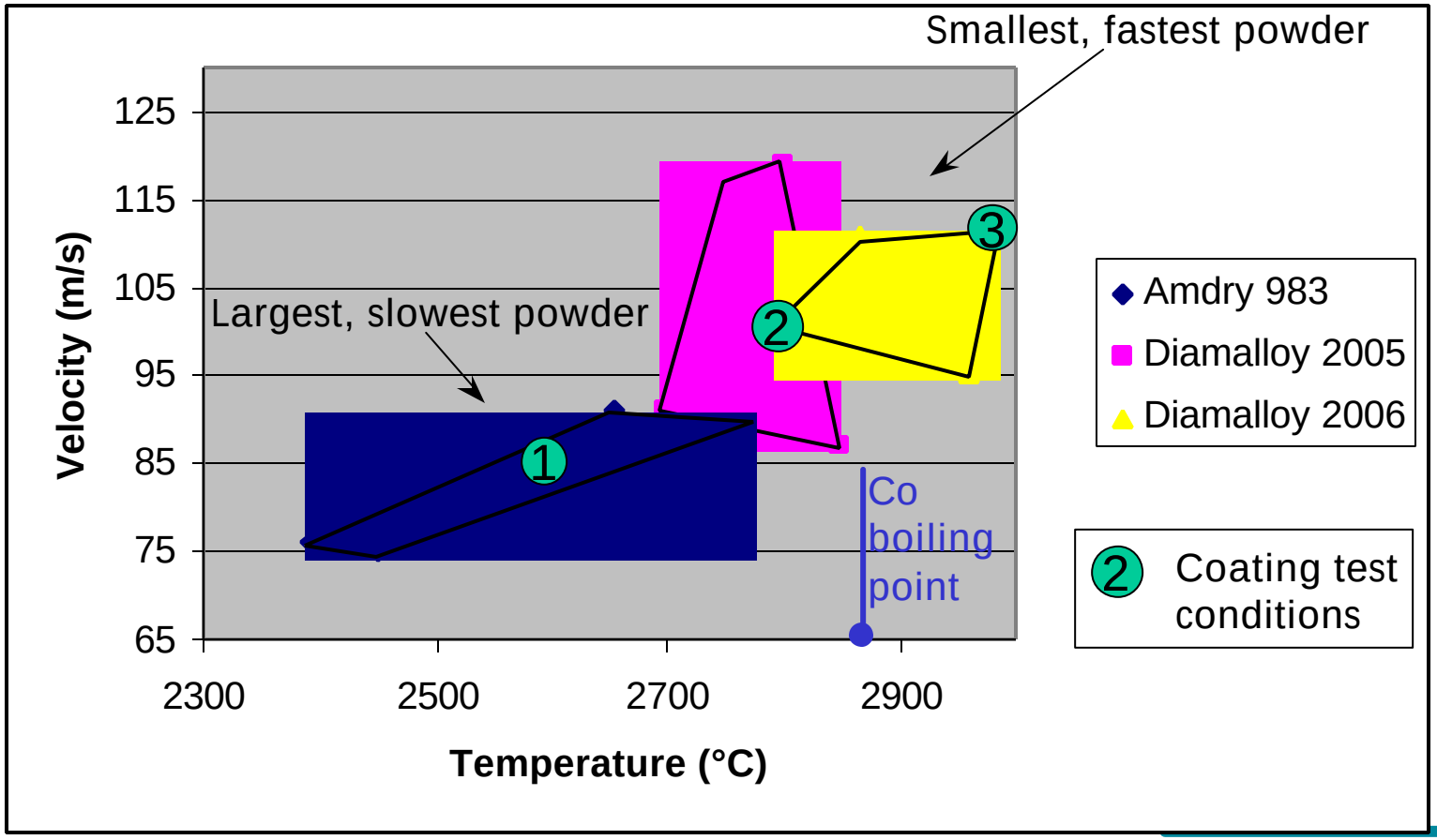
Operating Ranges
SM F-100 gun with 3 WC-Co powders



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Spray analysis - Amdry 983 powder

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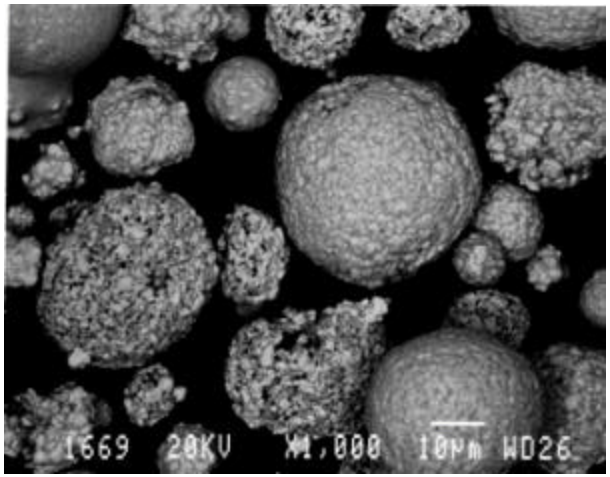

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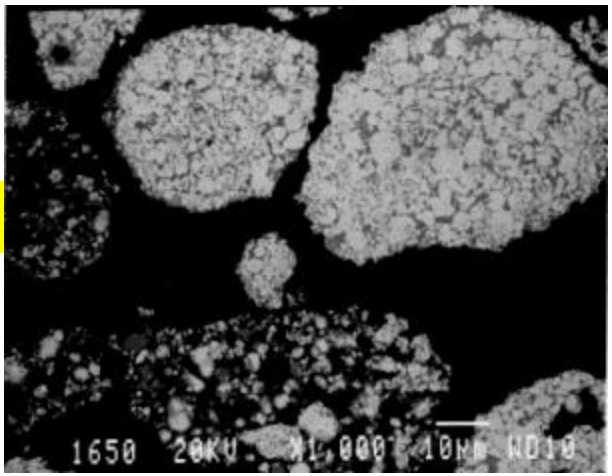

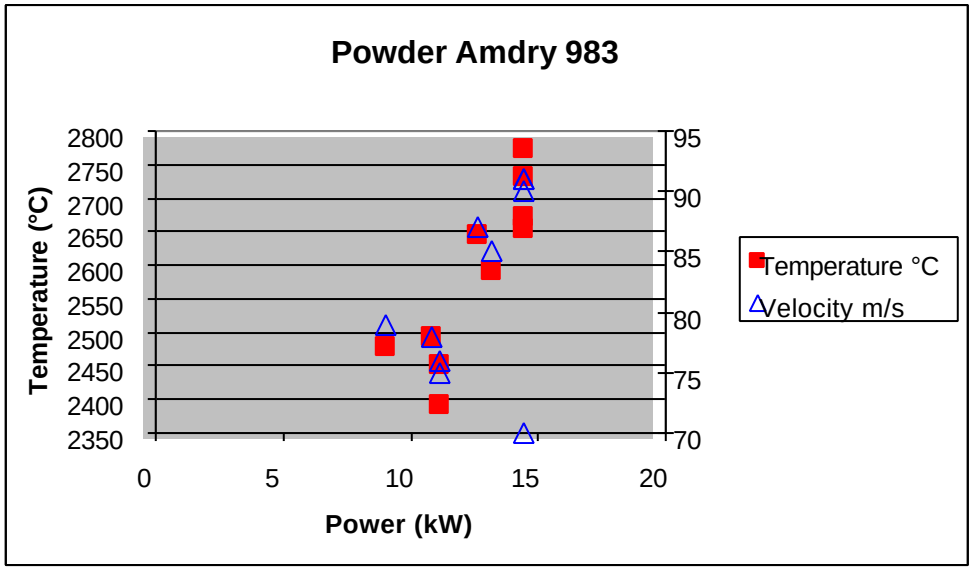

- Large, heavy agglomerates
- Relatively cool
  - Take a long time to heat up
- Relatively low velocity
  - Accelerate slowly in gas jet

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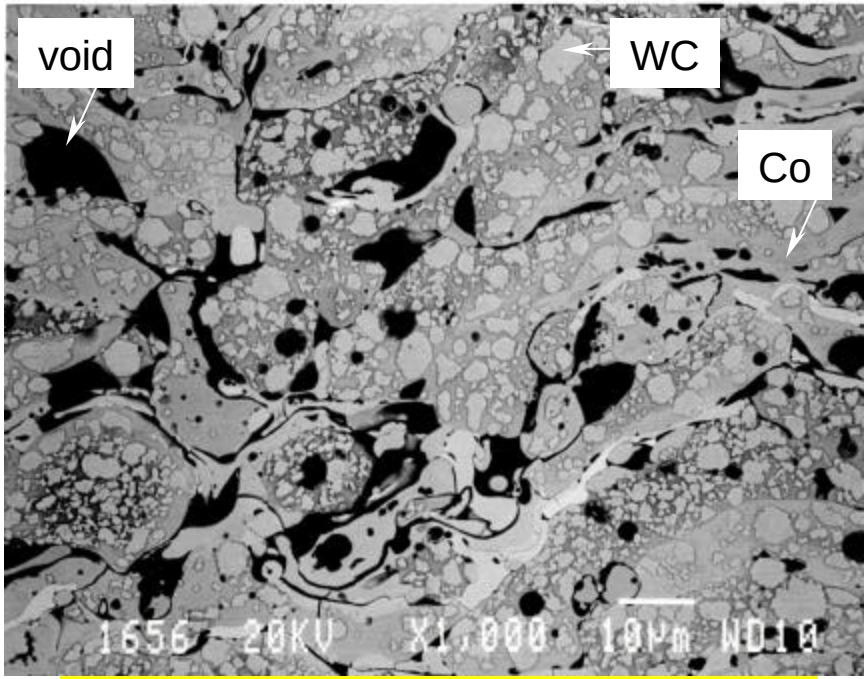
Amdry 983 coating (1)



SEM Cross-section - Backscattered

- Large, heavy particles
  - Lowest velocity particles (slowest acceleration)
  - Lowest temperature (highest thermal mass)
  - Carbides well-defined (not dissolved) because of low T
  - Porous because of low V

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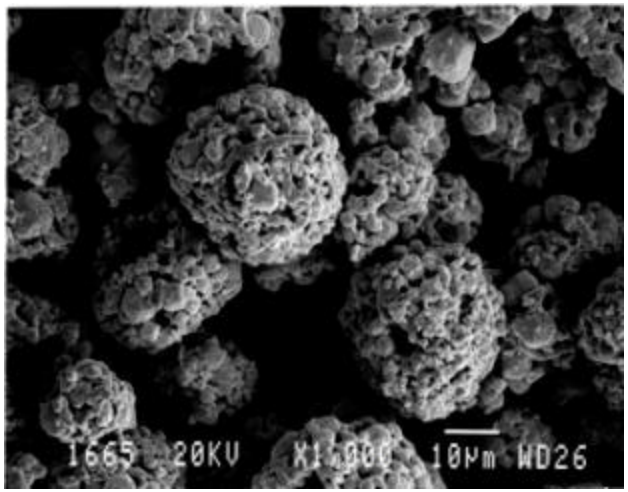
Spray analysis - Diamalloy 2005 powder

SEI



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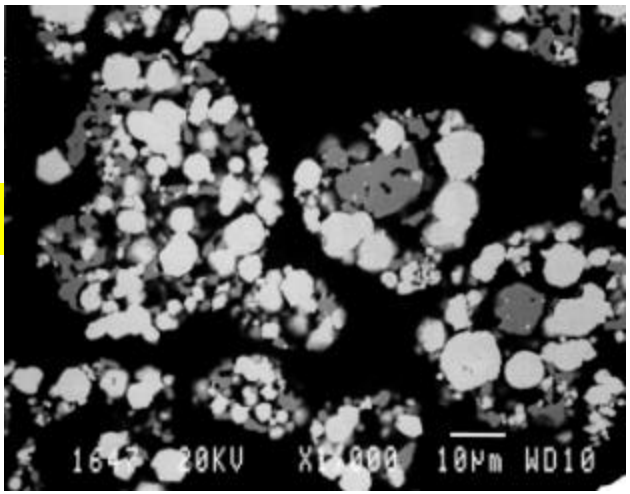

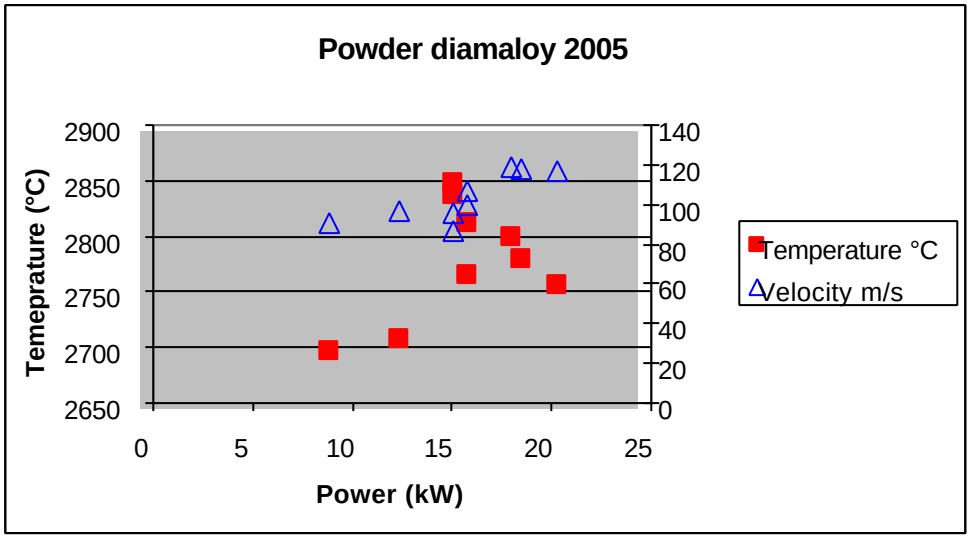

- Lower density particles
- Higher velocity
  - Rapid acceleration to full speed at nozzle exit
- Heat up more quickly
  - Reach higher temperatures

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Spray analysis example - Diamalloy 2006 powder

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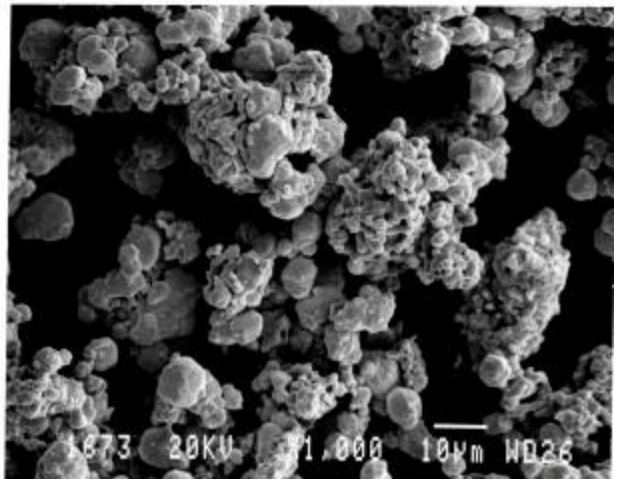

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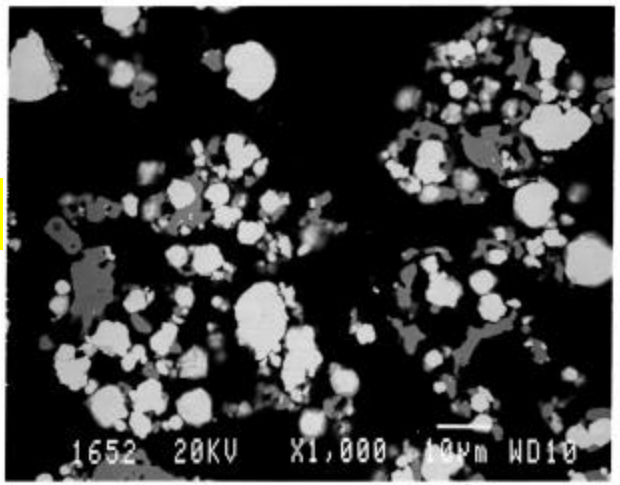

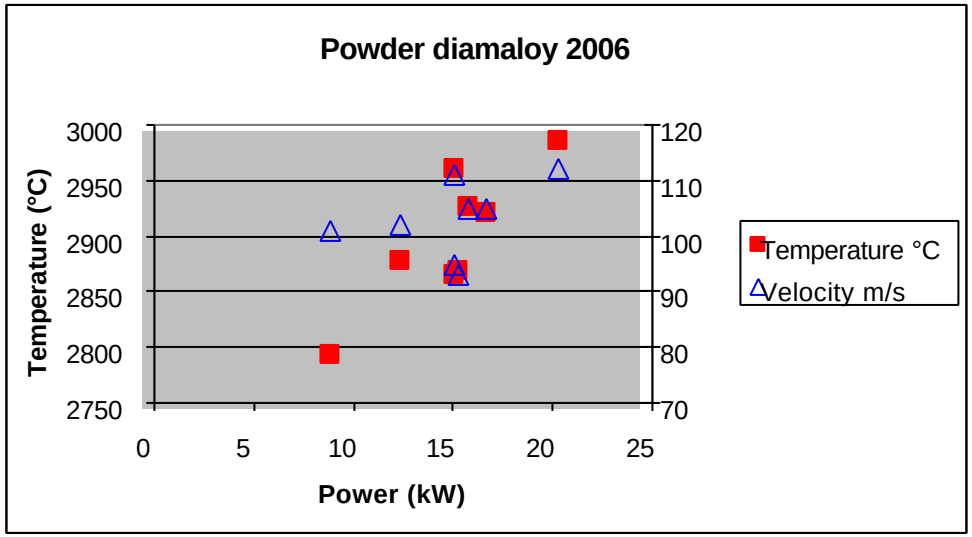

- Smallest particles
- Highest temperatures and velocities

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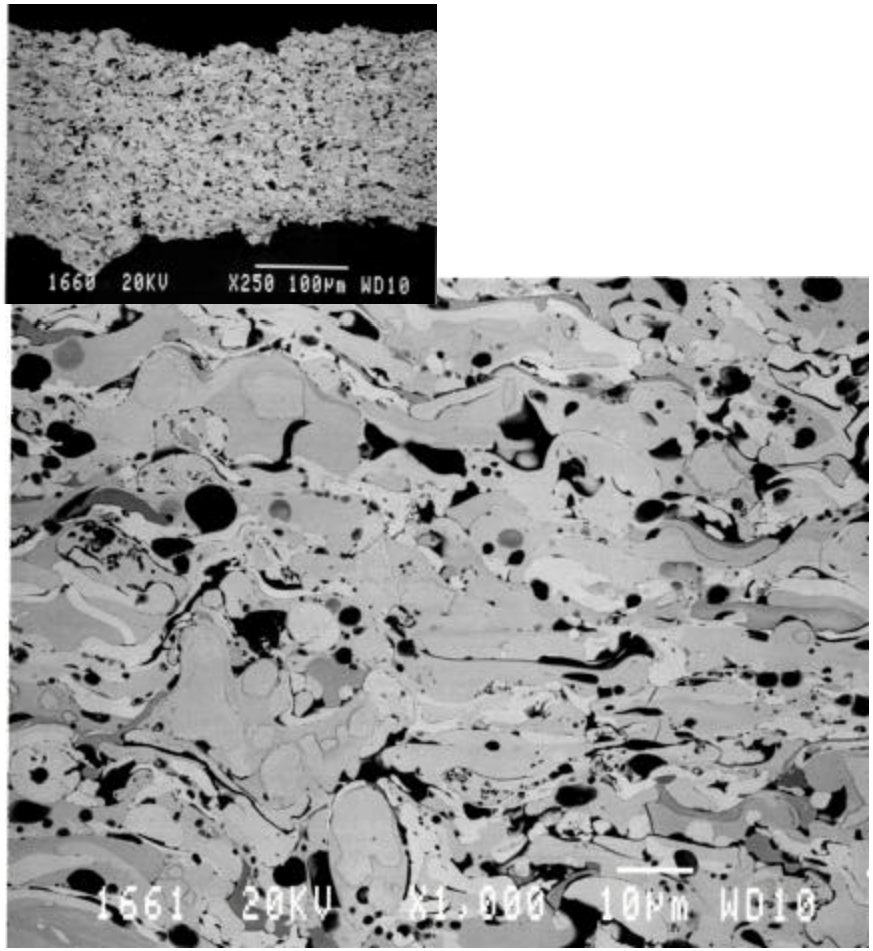
Diamalloy 2006 coating (3)



- Smallest particles
  - highest velocity and temperature
- Relatively low porosity
- Almost complete carbide dissolution
  - Far too high a particle temperature (Co partially evaporates away)

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Summary of particle temperature and velocity data

- Particle T and V vs spray conditions
  - Diamalloy V ~ 120ms^{-1} for most spray conditions
  - Amdry powder much heavier and slower
  - Smaller particles and higher velocities appear to give lower porosity, as expected
  - Can easily overheat and degrade WC, as expected, so need to control deposition conditions, stand-off etc.
    - Can define allowable ranges of temperature and velocity for different particle sizes and materials

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Conclusions from initial NRC study

- Behavior pretty much as expected
- Ideal powder different for different sized guns and different power levels
- Very easy to overheat powder with high-power gun
  - Especially with smaller powders
  - Result is WC dissolution
  - Need to aim for lower power, but with highest possible velocity to minimize porosity

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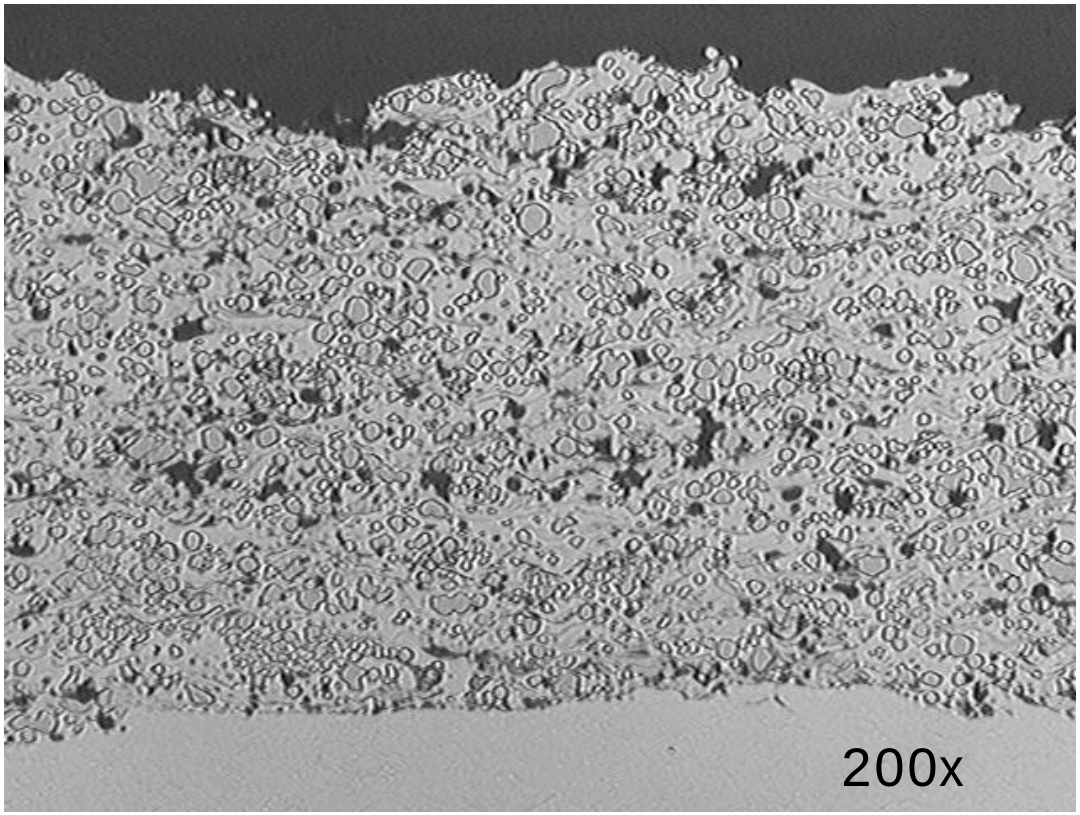
Sulzer Metco initial study

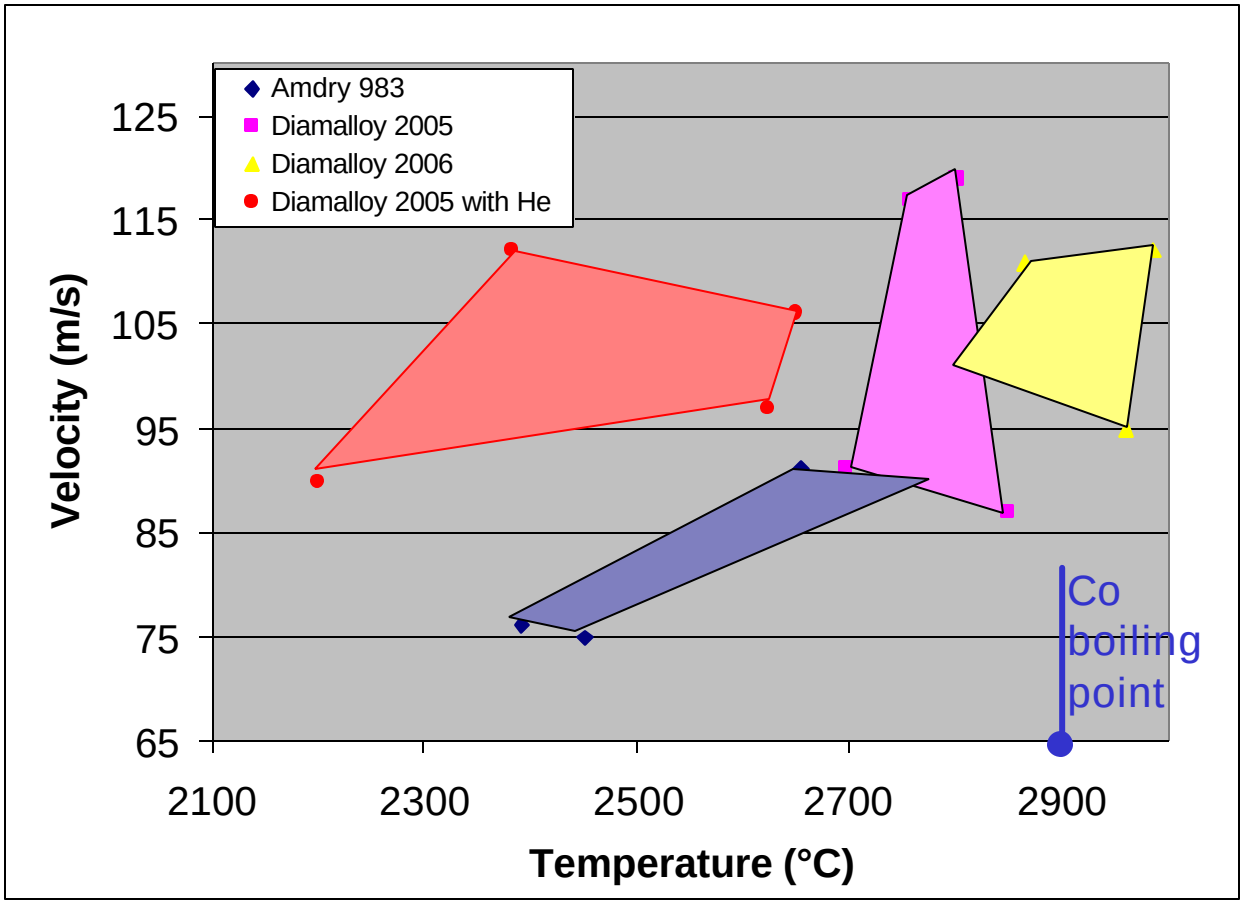
Run Number	Gun Type	Powder	Primary (Ar)	Second-ary (He)	Standoff (inch)	Power (kW)
91011-1	F-100	2005NS	45 SLPM	10 SLPM	1.25”	10.9
91011-2	F-100	2005NS	45 SLPM	20 SLPM	1.25”	11.2
91011-3	F-100	2005NS	45 SLPM	40 SLPM	1.25”	12.3
91011-4	F-100	2005NS	45 SLPM	80 SLPM	1.25”	14.0
91011-5	F-100	2005NS	45 SLPM	160 SLPM	1.25”	15.6
91011-6	F-100	2005NS	45 SLPM	200 SLPM	1.25”	16.3
91013-2	F-210	2005NS	45 SLPM	10 SLPM	1.5”	9.5
91013-3	F-210	2005NS	45 SLPM	20 SLPM	1.5”	10.5
91013-4	F-210	2005NS	45 SLPM	40 SLPM	1.5”	11.7
91013-5	F-210	2005NS	45 SLPM	80 SLPM	1.5”	12.6
91013-6	F-210	2005NS	45 SLPM	160 SLPM	1.5”	14.4

Sulzer Metco initial study



- Run 91011-1
  - low He, low kW
- Porosity 9%
- Hardness 764 HV_{300}
- Well-defined microstructure
- Optimization proceeding for both guns
  - coordinating with NRC

Diamalloy 2005 + He at NRC
Based on Sulzer Metco conditions



- He secondary gas allows
  - Lower T
  - Higher V
  - Good microstructure
- T and V to be measured closer to gun
- Optimization to be done on both guns
  - transfer to Sulzer Metco

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Praxair Tribaloy 400 initial testing

- 2700 gun
- 2” stand-off, 10-42 gpm
  - approx. 0.001”/min on 12” long x 3” ID tube
- Coated in 3” ID tube
- Three powders
  - -325 mesh (44 µm) baseline and -400 mesh (37 µm) smallest available
  - -500 mesh (30 µm)
    - Produced for project
  - Porosity greatly improves as go from standard 44 µm to 30 µm powder
    - fine powder harder to feed
- To be done next
  - Measure properties of coatings so far
  - Develop parameters and coat ID with 30 µm powder
  - Improve powder feed for fine powder

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Conclusions so far

- Coating deposition behaves pretty much as expected
  - Have enough power to easily overheat powder with F100 gun
  - However, addition of He reduces T while maintaining V
  - Can make reasonable quality WC-17Co coatings
  - Beginning to make reasonable quality T400 coatings
  - As expected, powder feed more difficult with small powders
  - Can coat at high rate
  - We are now in position to optimize and make samples for process development
- NRC now has sample holder and Praxair, Sulzer Metco guns needed for output characterization and optimization

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